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Agricultural Memorandum No 823

The effect of Crop Height on Transpiration

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Agricultural Memoranda 369 and 374A attempted to express the variation of transpiration with crop height using a dubious procedure. Recently, Thom and Oliver (1977) have given a discussion of Penman's formula from which it is now possible to obtain some idea of the variation of transpiration with crop height on a surer footing.

Thom and Oliver re-wrote Monteith's version of Penman's formula as

$$E = \frac{(\Delta\, Qn + [(\ln(Z/1.37))/(\ln(Z/Zo)]^2\, \gamma\, Eap)}{[\Delta + \gamma\,(1+r_s/r_a)]} \qquad (1)$$

E is the mass flux of water vapour

Qn is net radiation

Z is height (mm)

Zo is the crop roughness length (mm)

Eap is the aerodynamic term originally specified in Penman's formula

r_s is the resistance to vapour flow within the leaf.

r_a is the resistance to vapour flow from the crop surface to the height Z.

They also give a generalized expression for r_a as

$$r_a = \frac{r_{ap}}{[(\ln(Z/1.37))/(\ln(Z/Zo))]^2} \qquad (2)$$

r_{ap} is Penman's original formulation of aerodynamic resistance.

We are interested in assessing transpiration from a tall crop relative to a short one. If we take the short crop as grass 20 cm tall for which $Zo \simeq 20$ mm then transpiration figures obtained from Technical Bulletin 16 of MAFF can be equated to transpiration from grass 20 cm tall with little error.

If Es and Et are the transpirations from the short and tall crops respectively then the ratio Et/Es can be obtained from eq (1) if everything is specified. In midsummer in southern England the following values are assumed (Page 72-3 Technical Bulletin 16):

Qn = 3.15 mm/day
Eap = 2.48 mm/day
Mean wind speed, U = 3 m/s
For gross with Zo = 20 mm and Z = 2000 mm, $r_a \doteq 40$ s m^{-1}
For crop 2 m high Zo = 200 mm then $r_a \doteq 10$ s m^{-1}; for a crop 1 m high $r_a \doteq 17$ s m^{-1}

There now remains the problem of specifying r_s. Grant (1975) measured r_s for barley and his figures suggest that r_s = 30-50 s m^{-1} for soil moisture deficits below about 75 mm, about 75 s m^{-1} from 75 to 125 mm soil moisture deficit and 100-200 s m^{-1} for deficits above about 125 mm. This gives us an idea of the sort of

r_s values to be used. It has to be assumed that the r_s values for the short and tall crop are the same.

The special case $r_s = 0$ is when the surface of the crop is thoroughly wetted by rain.

The following table gives the ratio E_t/E_s for the conditions specified above.

r_s s m^{-1}	Tall crop 1 m high	Tall crop 2 m high
0	1.70	2.55
50	1.21	1.33
100	1.04	1.06
200	0.91	0.88
500	0.81	0.74

This means that water lying on the leaves of a crop which is thoroughly wet can evaporate at rates more than double the potential evaporation rate. Even when the crop imposes some resistance to vapour flow a tall crop still transpires at a higher rate. A reversal occurs above about 120 s m^{-1} resistance. Above this resistance a tall crop transpires less than a short crop with presumably a greater production of sensible heat.

Application to Maize

In order to develop a model of water use by maize some idea of transpiration from the crop in different months had to be obtained. Clearly, intercepted rain evaporates at the highest rates, but since intercepted rain never wets all the plant surfaces some reduction below the E_t/E_s value for $r_s = 0$ would seem sensible. For maize 2 m tall intercepted rain was assumed to evaporate at twice the short crop rate, and for maize 1 m high at 1.5 the short crop rate.

Suggested Scheme for Transpiration/Evaporation from Maize

We now have an idea of the increases in transpiration for tall crops over short crops (for r_s values less than 100 s m^{-1}), and now we need some idea of how E_t varies with r_s at a given crop height. Equation (1) can be used again with typical values of r_s corresponding to different soil moisture deficits as obtained from Grant (1975). The following scheme is proposed, where E is the evaporation/transpiration rate. P is the potential transpiration applicable to the short crop (grass).

April and May

Bare soil is assumed.

First	25 mm of soil moisture	E = P
Next	8 mm " " "	E = 0.3P
Next	2 mm " " "	E = 0.1P

(From Ag. Memo 580 by C. V. Smith)

June

First 35 mm of soil moisture		E = P
Next 35 mm " " "		E = 0.5P
Next 25 mm " " "		E = 0.25P

Allows for increasing root depth as the seedlings grow.

July

Intercepted rain evaporates at E = 1.5P (maximum interception = 0.5 mm). Then:

First 75 mm of soil moisture	E = 1.2P
Next 50 mm " " "	E = 0.5 (1.2P)
Next 25 mm " " "	E = 0.25 (1.2P)

August and September

Intercepted rain evaporates at E = 2P (maximum interception = 0.5mm) Then:

First 75 mm of soil moisture	E = 1.3P
Next 50 mm " " "	E = 0.5 (1.3P)
Next 25 mm " " "	E = 0.25 (1.3P)

Any comments or suggestions on this paper should be referred to the author.

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February 1978

References

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Thom, A.S., Oliver, H.R. 1977 On Penman's equation for estimating regional evaporation. Quart. J. R. Met. Soc. 103, pp 345-357.